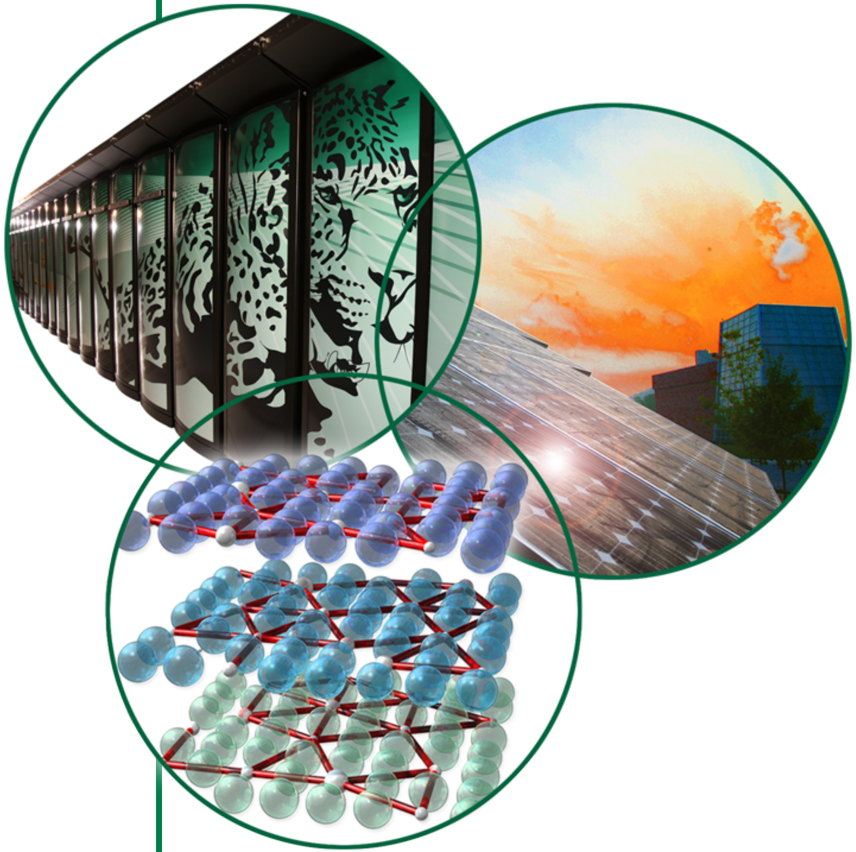
SNS Operational Experience



Project X Workshop

April 12, 2011

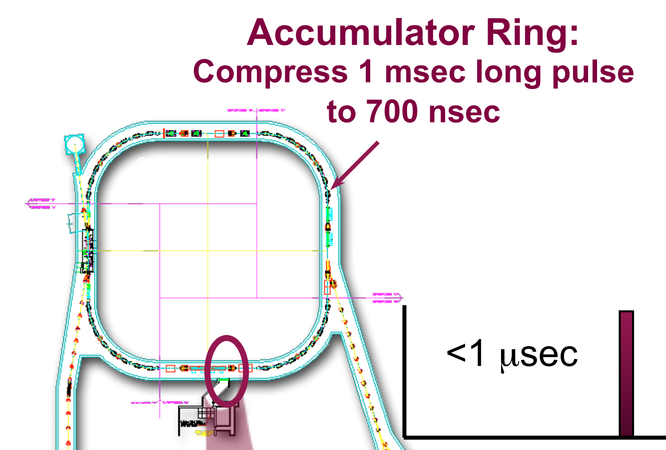
Kevin Jones – on behalf of the SNS team

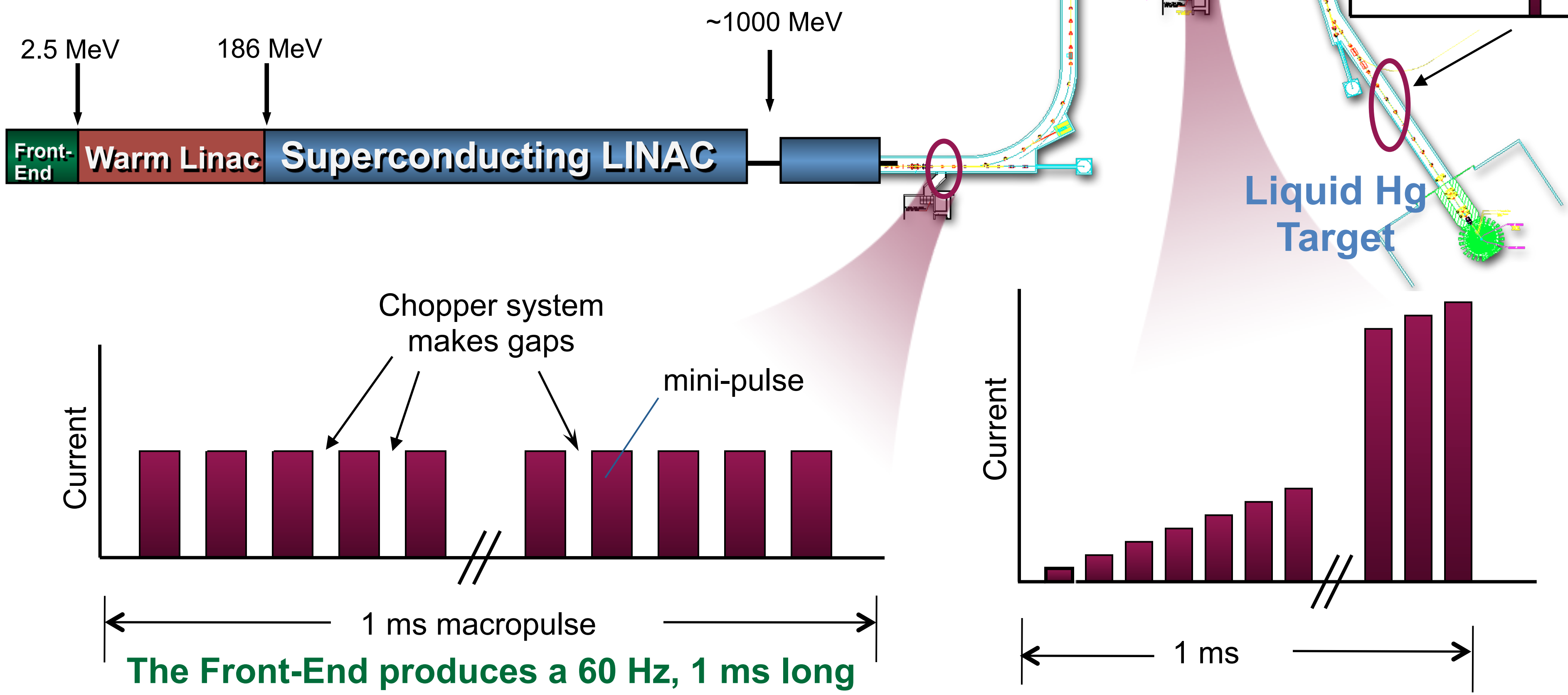
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

SNS Accelerator Complex

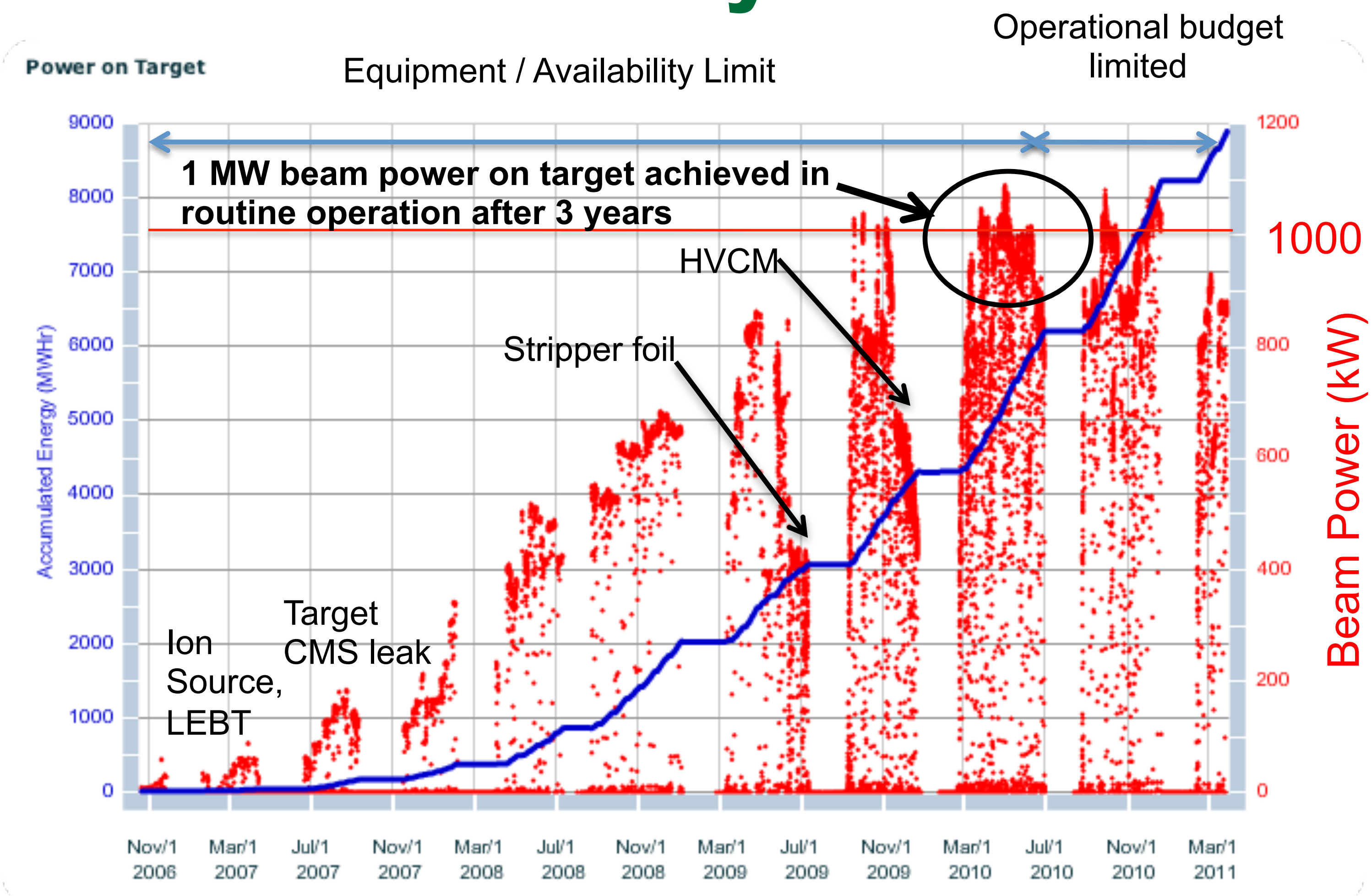
- The SNS accelerator is the highest power pulsed hadron linear accelerator
  - Uses superconducting RF for acceleration
  - Storage Ring to compress the 1 ms linac beam into a 1 μs "short-pulse" on the neutron production target





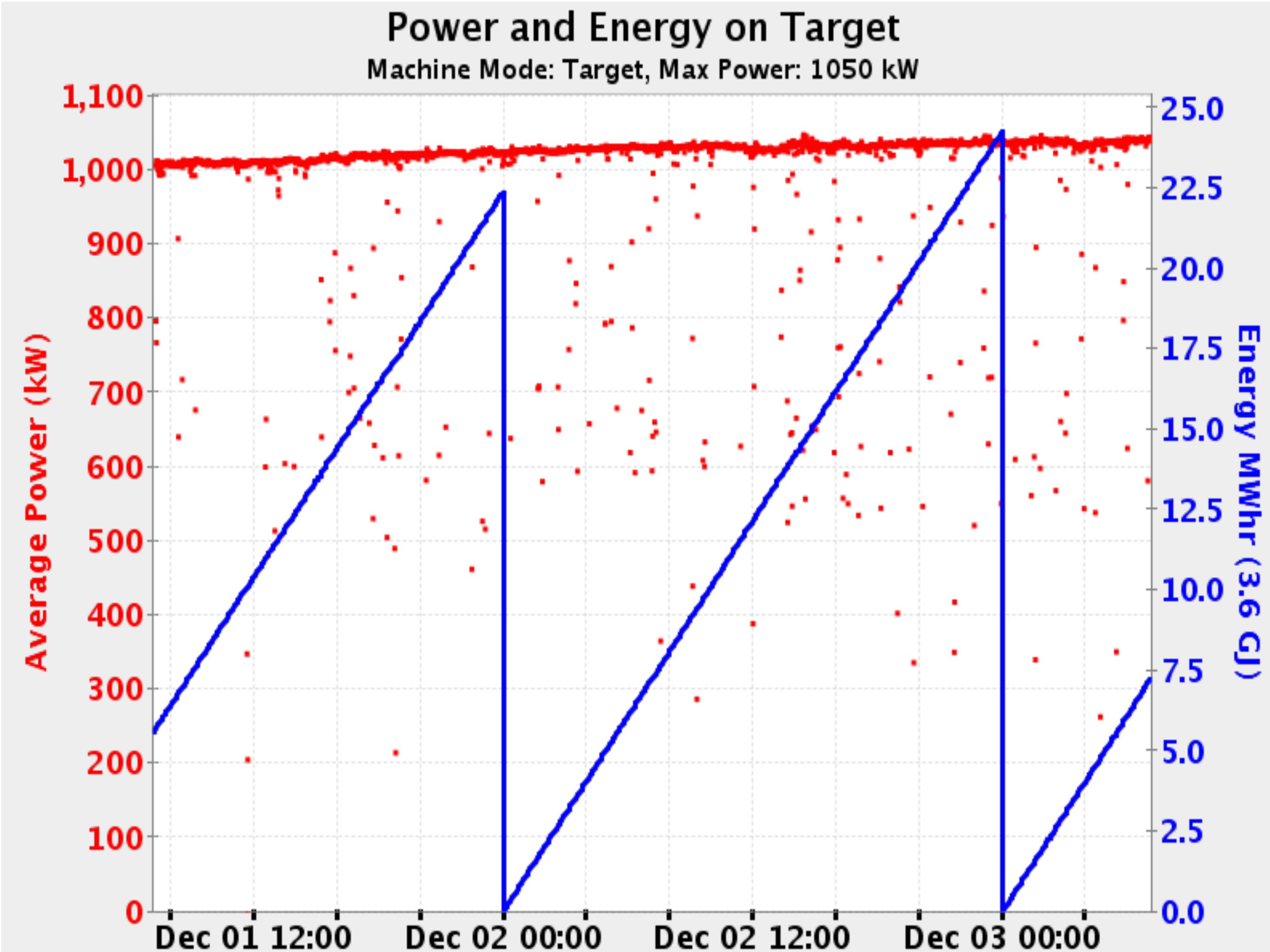
The Front-End produces a 60 Hz, 1 ms long chopped H- beam

Beam Power History

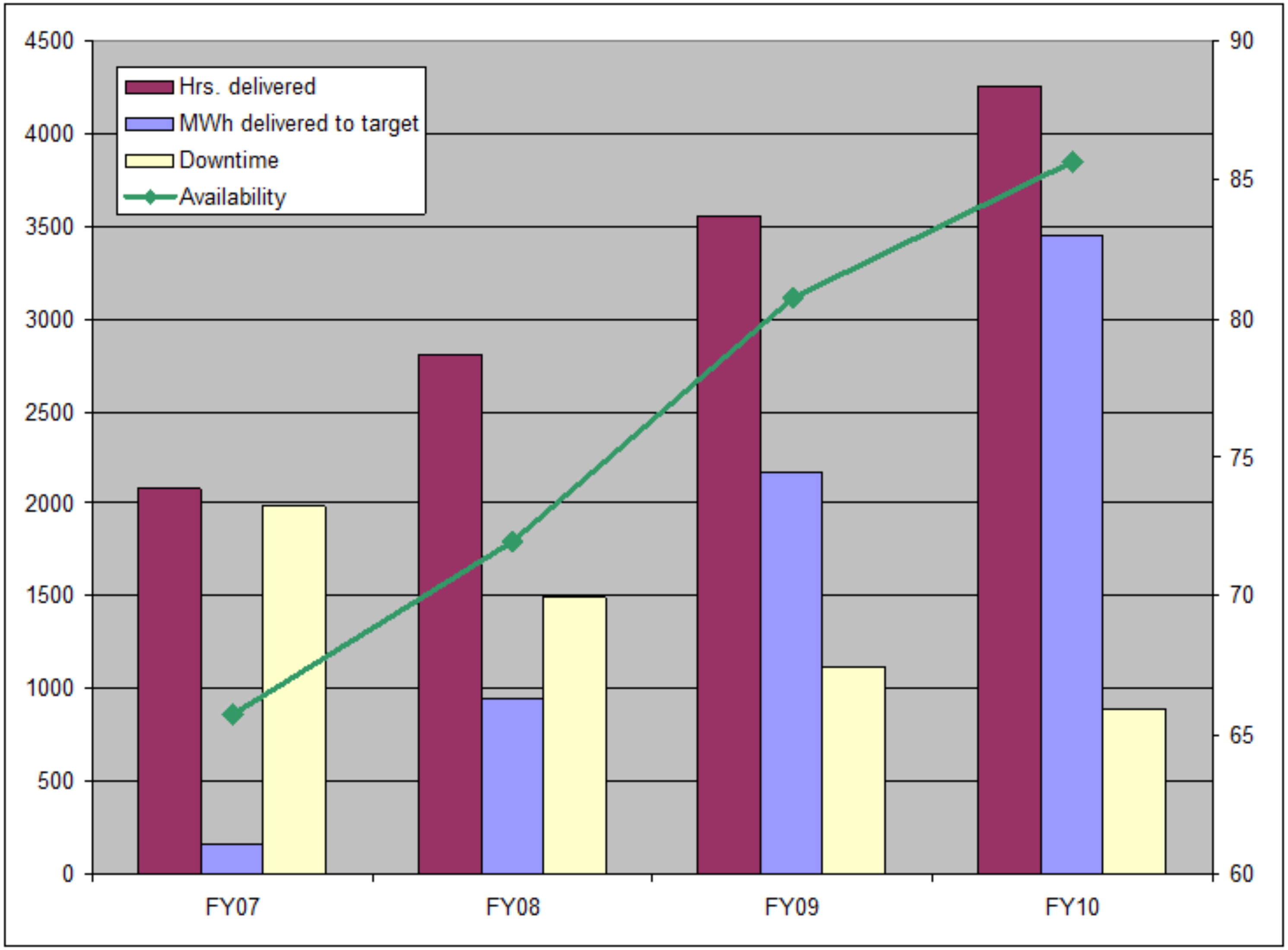


- **Running at ~ 1 MW for ~ 1.5 years**
- **Present operational power is dictated by budget allowance**
  - **Not limited by equipment or beam loss!**

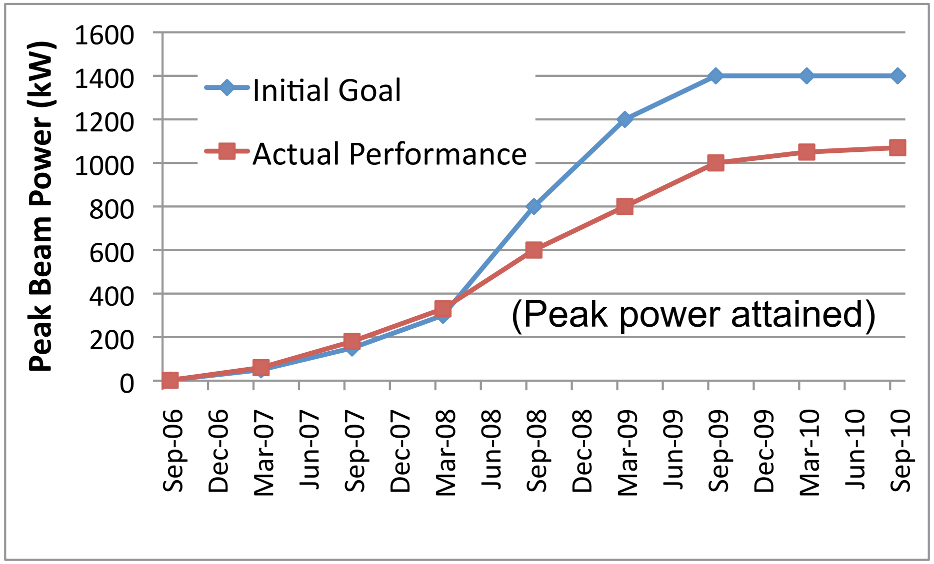
SNS has demonstrated reliable operation at ~1 MW



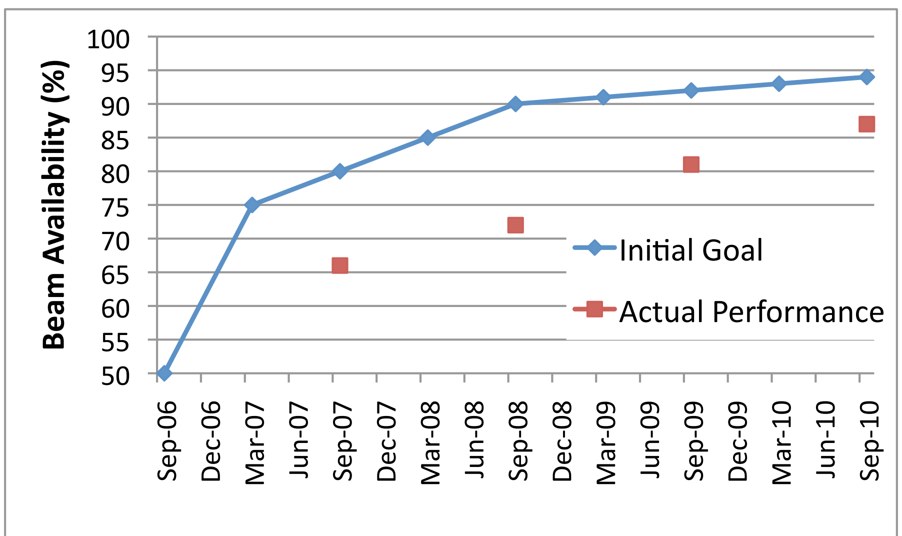
Since 2006 operational performance improvement at SNS has been dramatic



Our ramp-up goals were adjusted to meet user expectations and match budgets

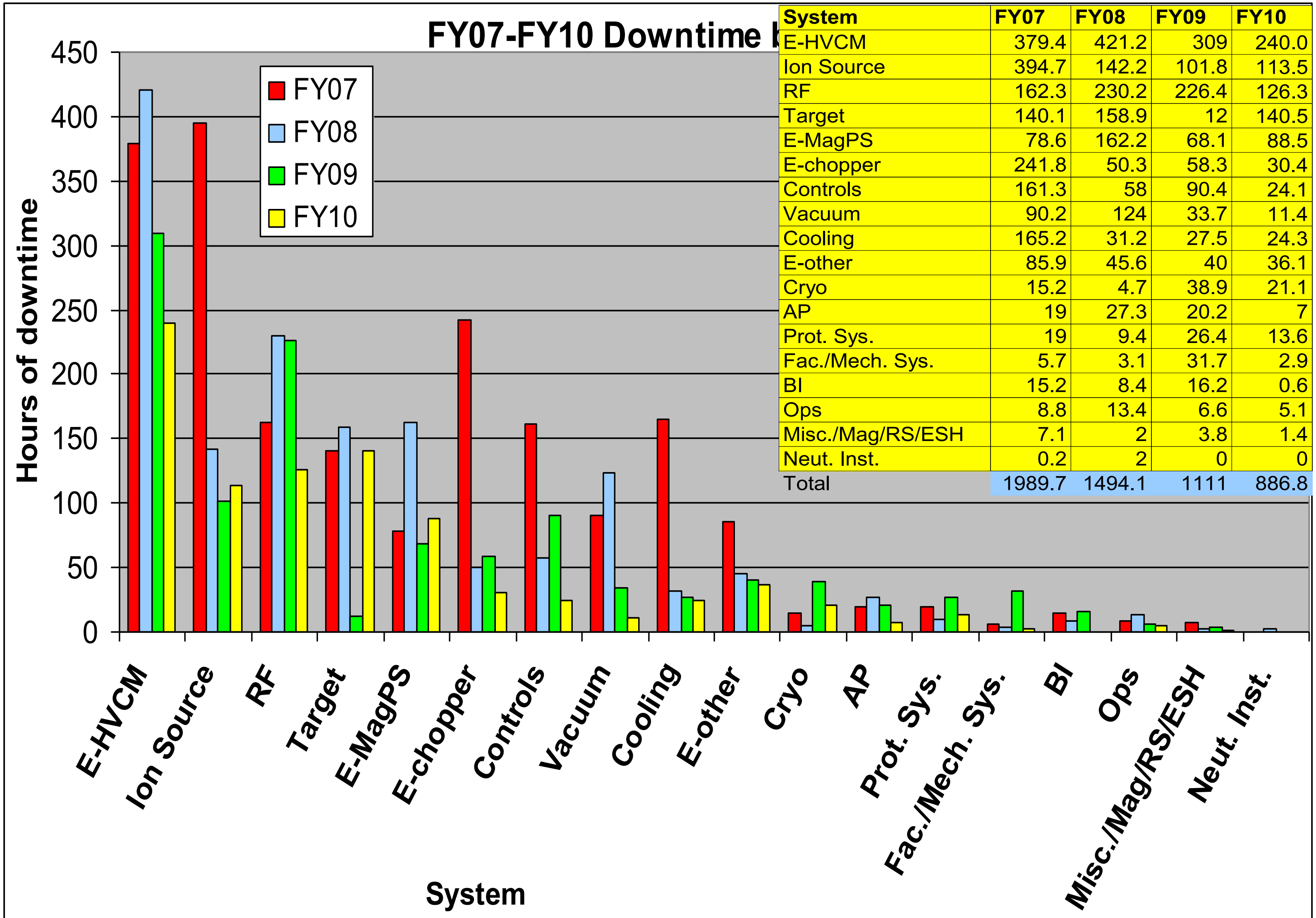


- Beam power: kept up initially, but leveled off at ~ 1 MW after fall 2009



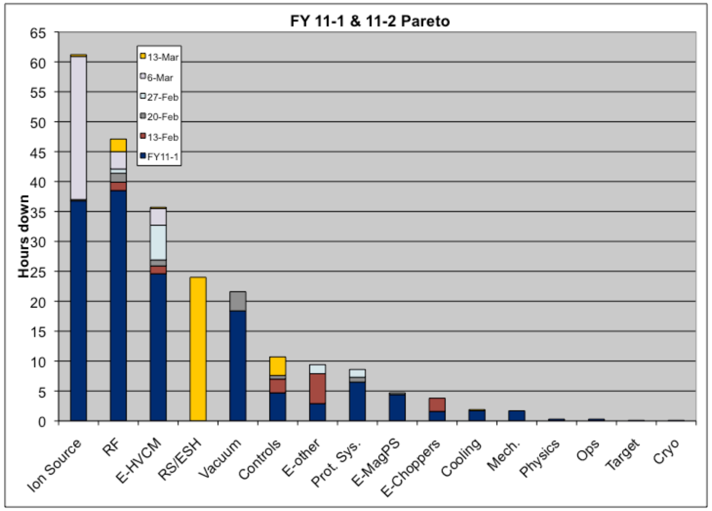
- Availability is a more difficult goal, and stronger driver for operational parameters
  - We could run at higher powers, but the availability may suffer

Initial and ongoing operation revealed system weakness that have been substantially addressed

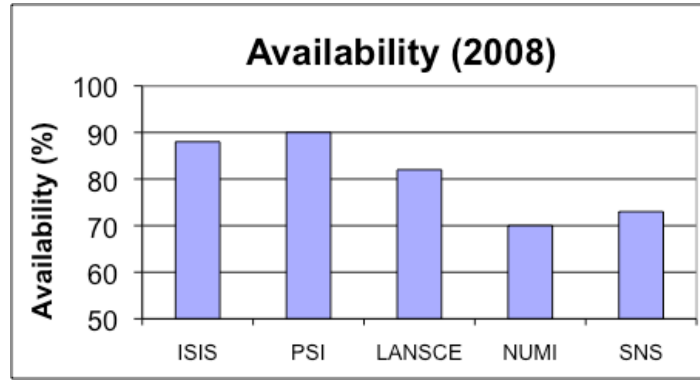


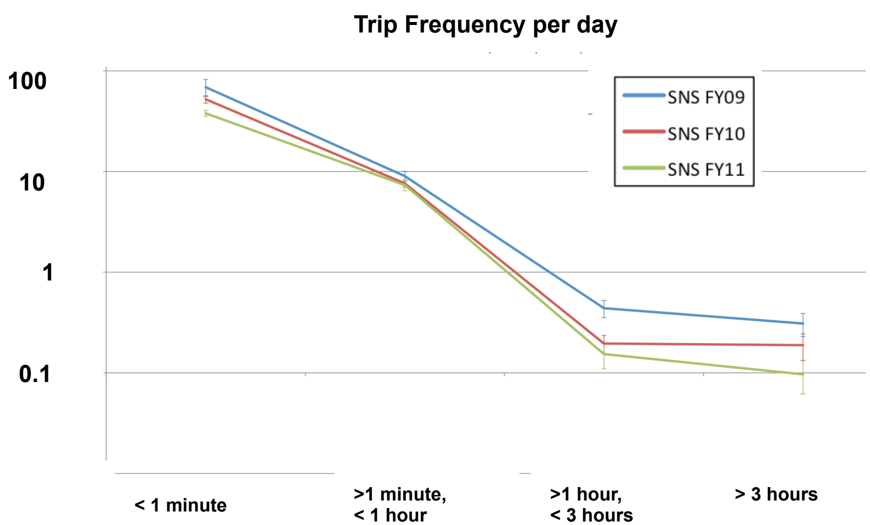
System	FY07	FY08	FY09	FY10
E-HVCM	379.4	421.2	309	240.0
Ion Source	394.7	142.2	101.8	113.5
RF	162.3	230.2	226.4	126.3
Target	140.1	158.9	12	140.5
E-MagPS	78.6	162.2	68.1	88.5
E-chopper	241.8	50.3	58.3	30.4
Controls	161.3	58	90.4	24.1
Vacuum	90.2	124	33.7	11.4
Cooling	165.2	31.2	27.5	24.3
E-other	85.9	45.6	40	36.1
Cryo	15.2	4.7	38.9	21.1
AP	19	27.3	20.2	7
Prot. Sys.	19	9.4	26.4	13.6
Fac./Mech. Sys.	5.7	3.1	31.7	2.9
BI	15.2	8.4	16.2	0.6
Ops	8.8	13.4	6.6	5.1
Misc./Mag/RS/ESH	7.1	2	3.8	1.4
Neut. Inst.	0.2	2	0	0
Total	1989.7	1494.1	1111	886.8

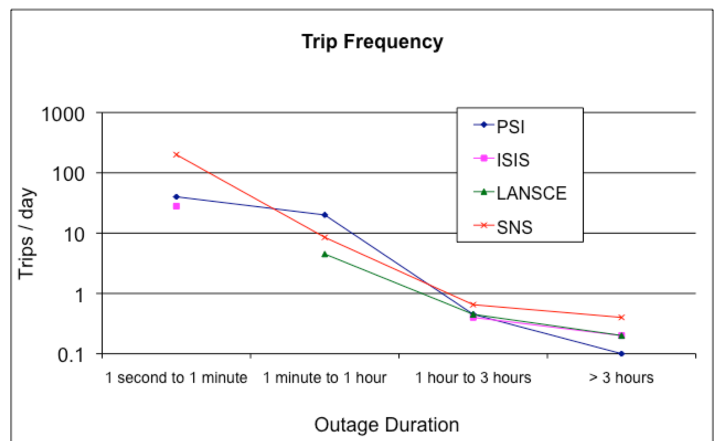
SNS reliability compares favorably with other moderate to high-power facilities



Data compiled at the 2008 ICFA High Brightness workshop, Nashville TN

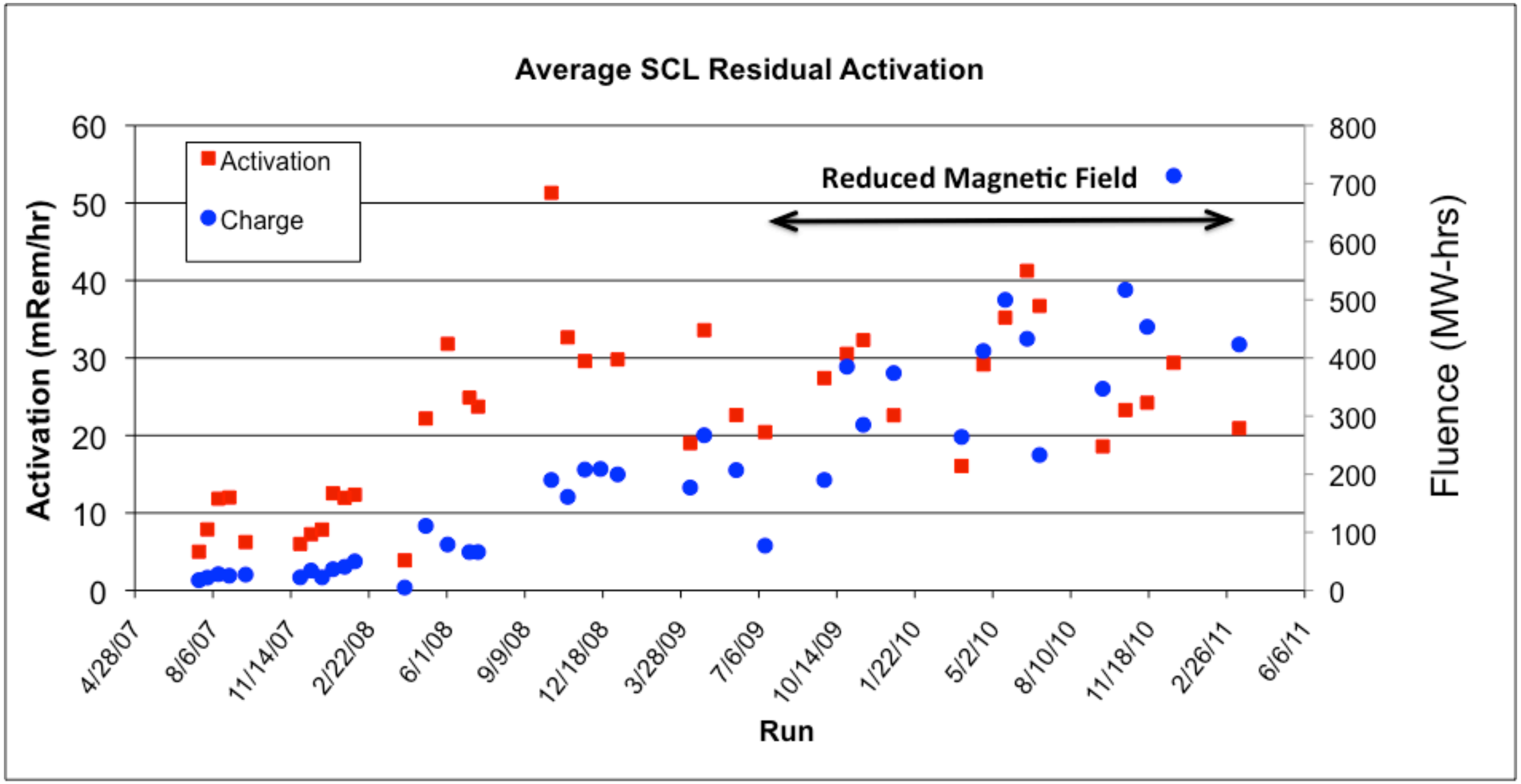






- **Facilities with the fewest long outages have the highest availability**

Linac Activation History

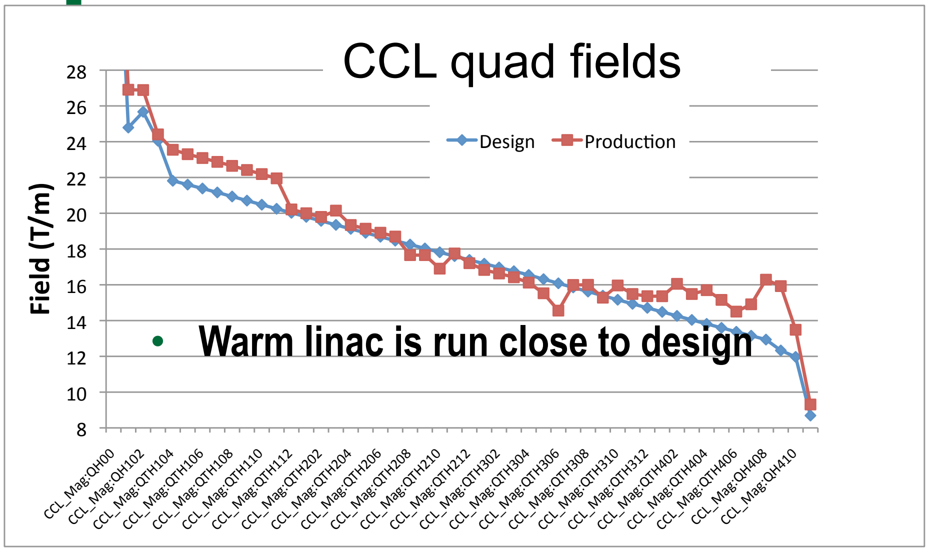


- **Superconducting Linac activation is not increasing, despite significant increase in power and operational hours**
- **Beam loss is not a limiting factor (at least for 1 MW beam)**

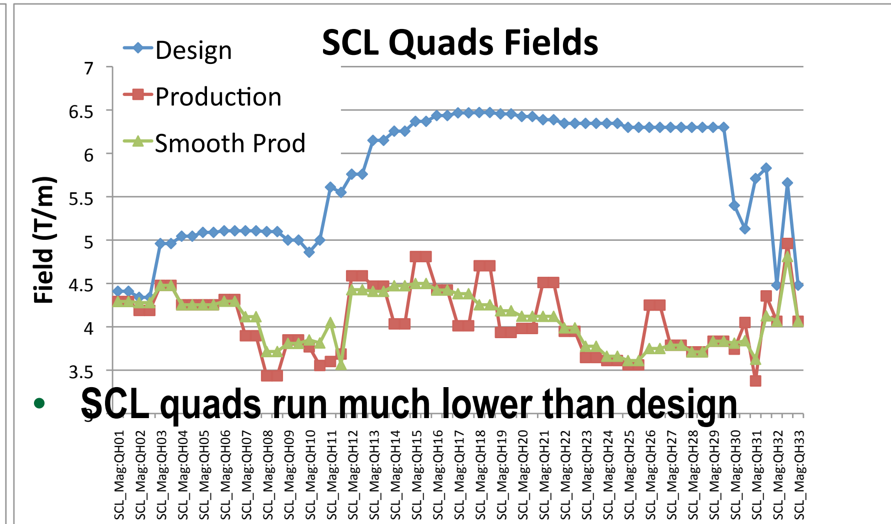
How Much Beam is Lost in the SNS SCL ???

- We did not know what to expect
  - models indicated no loss, but…
- Activation measurements indicate < 1 W/m in the warm sections between our cryo-modules
  - $< 10^{-4}$ of the beam throughout the superconducting linac
- Measurements in the 10^{-5} fractional beam level are difficult
  - Loss monitors are quite sensitive, but do not tell you much about why you lost beam
- Laser profile device turns out to be a good way to create controlled beam spills of 10^{-6} beam
  - Increases the integrated beam loss about 10% (or we are nominally losing 10^{-5} throughout the linac)

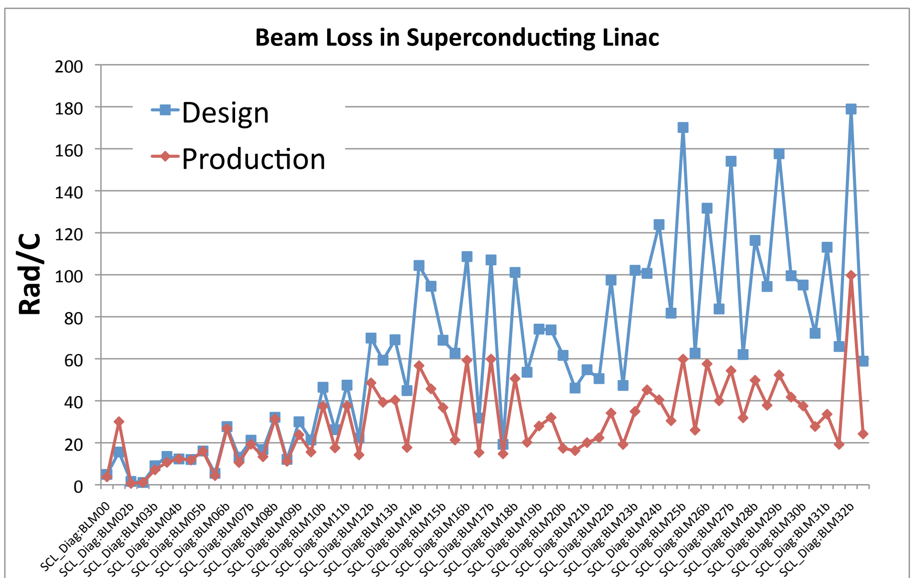
SNS Linac Transverse Lattice: Design vs. Operation



- Warm linac is run close to design



- SCL quads run much lower than design

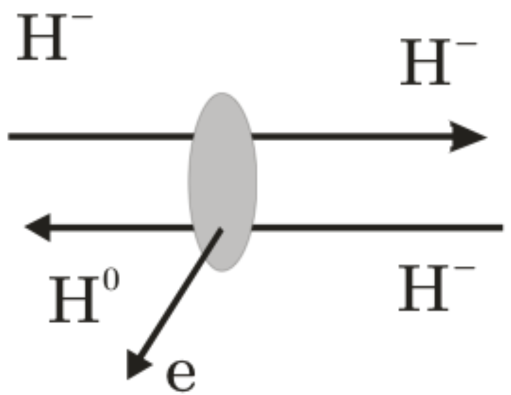


- SCL beam loss is significantly lower for the reduced field settings!!
- Empirically derived

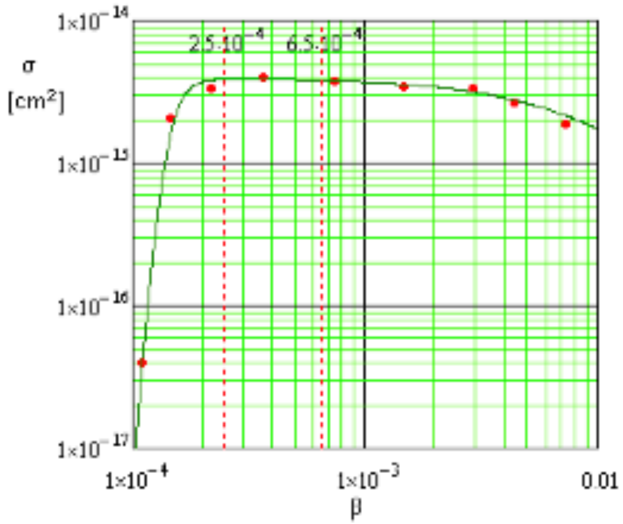
Intra-Beam-Scattering Beam Loss

V. Lebedev, FNAL

Collisions between H- in the accelerated bunch can strip the outer electron



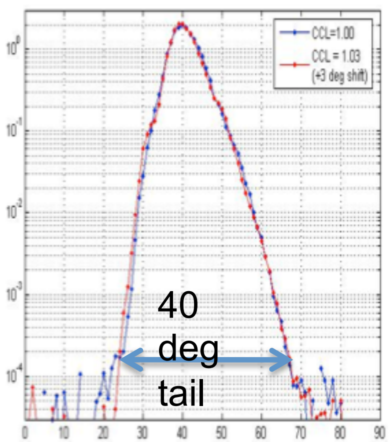
Stripping probability is known :



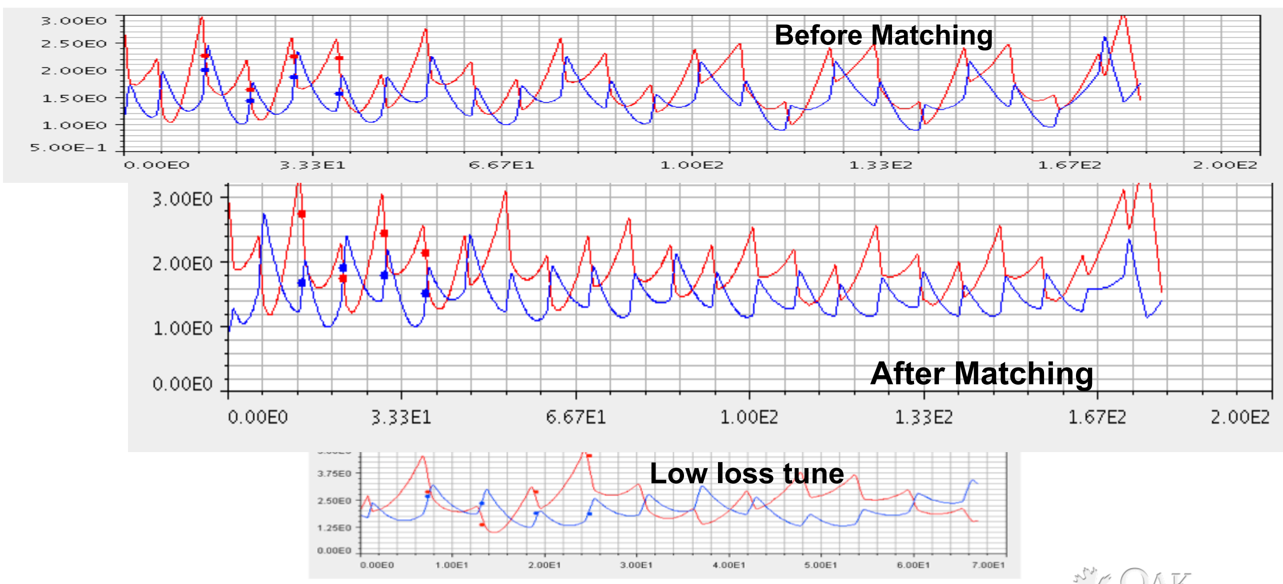
- **Simple estimates indicate this could be a loss contributor at SNS**
- **Only an issue for H^- beams**
  - **Considered a proton source experiment to test this loss mechanism**
  - **Now planning on a low energy foil (strip H- to p) experiment**

Linac Beam Loss Situation

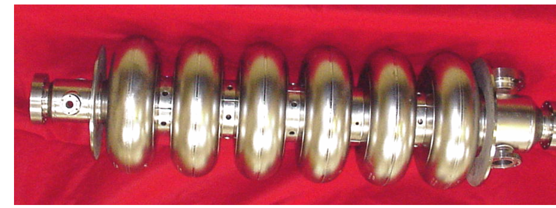
- SNS has unexpected beam loss in the SCL
  - OK for 1 MW, not acceptable for 10 MW
  - There is a suite of measurement tools available at SNS
  - Challenge is to measure the 6-D initial beam distributions down to halo levels
  - And understand measured beam loss
- We should use the existing machines to understand the nature of this loss



Longitudinal BSM, S. Aleksandrov

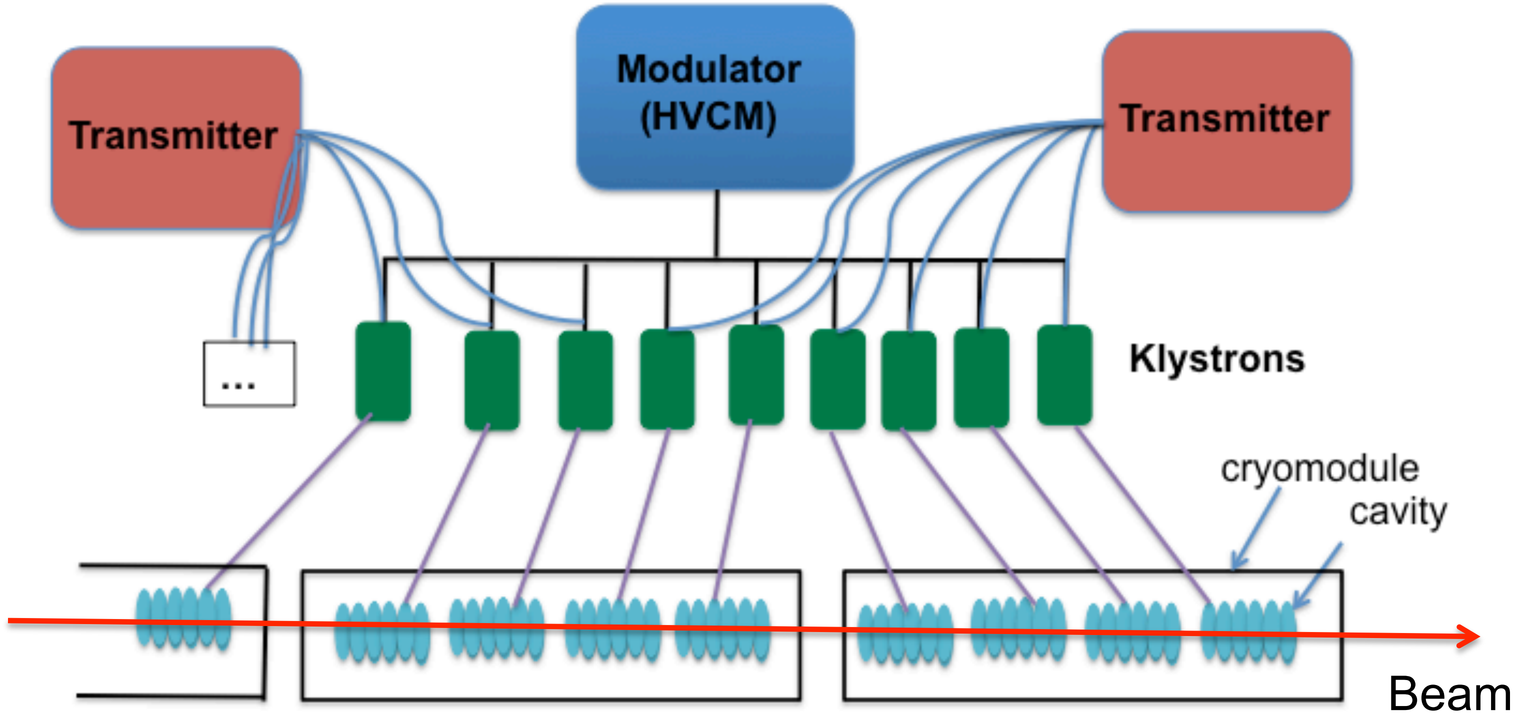


SNS Superconducting Linac



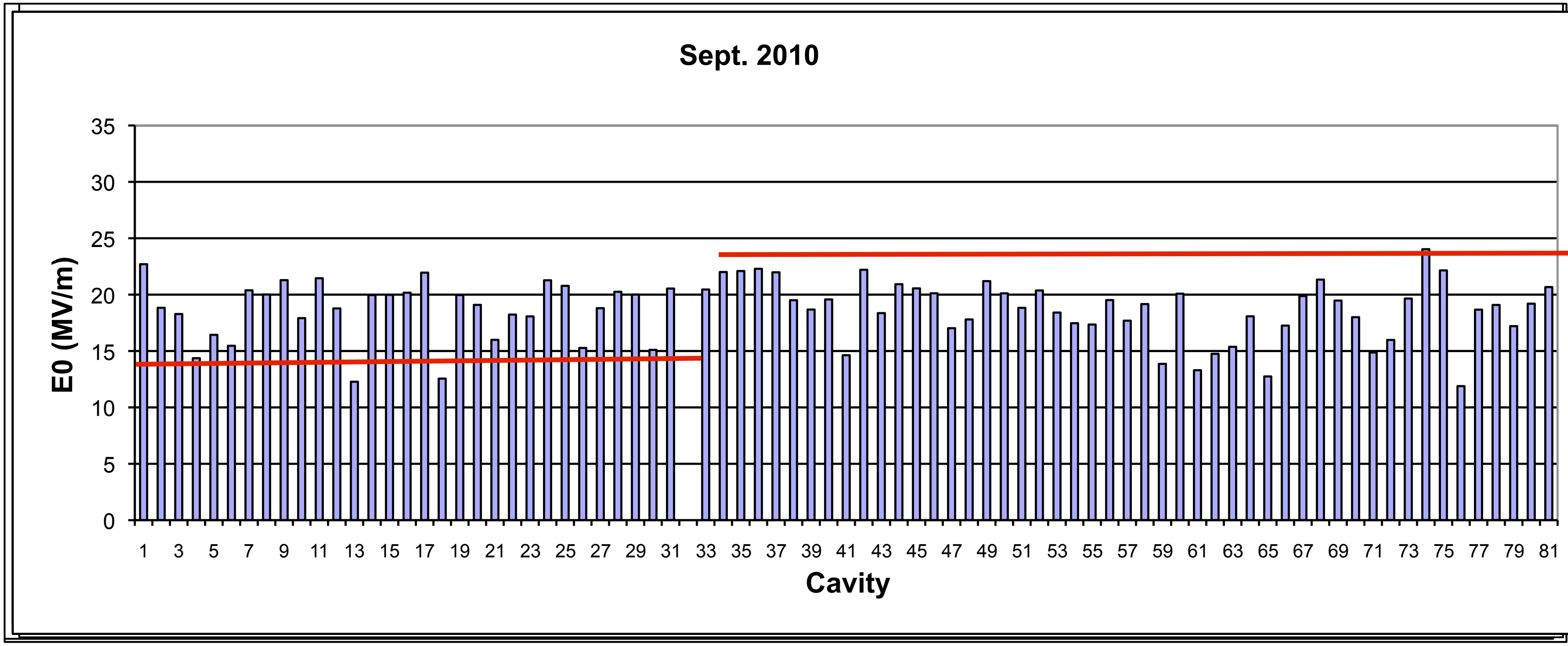
- 160 m, 23 cryo-modules, 81 cavities
- Operating at 1 MW, 925 MeV, 60 Hz, 5% beam duty cycle

SNS RF Layout



- One cavity / klystron: easy, flexible, expensive
- High voltage drive and transmitters are common-mode failure points though
  - Alternatives include hot spare, single power supply / RF source

Superconducting Cavity Amplitudes



- SCL cavity gradient levels were not what we expected
  - We grossly underestimated the gradient variability
  - But the SCL is operationally quite flexible !!
    - Make sure there is enough margin in the cavity design gradient

RF System: Independently Powered Cavities

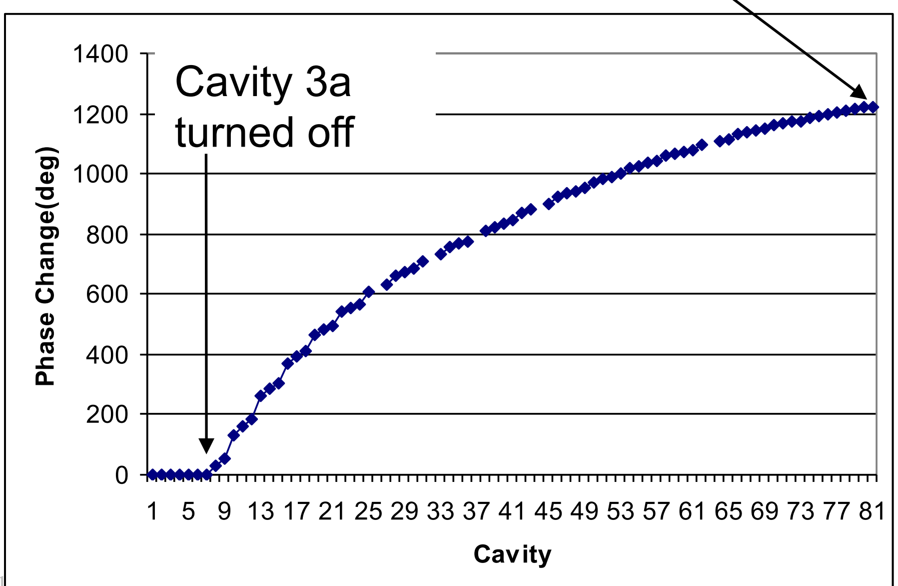
81 x 550 kW klystrons

- **One klystron per cavity: conservative but robust**

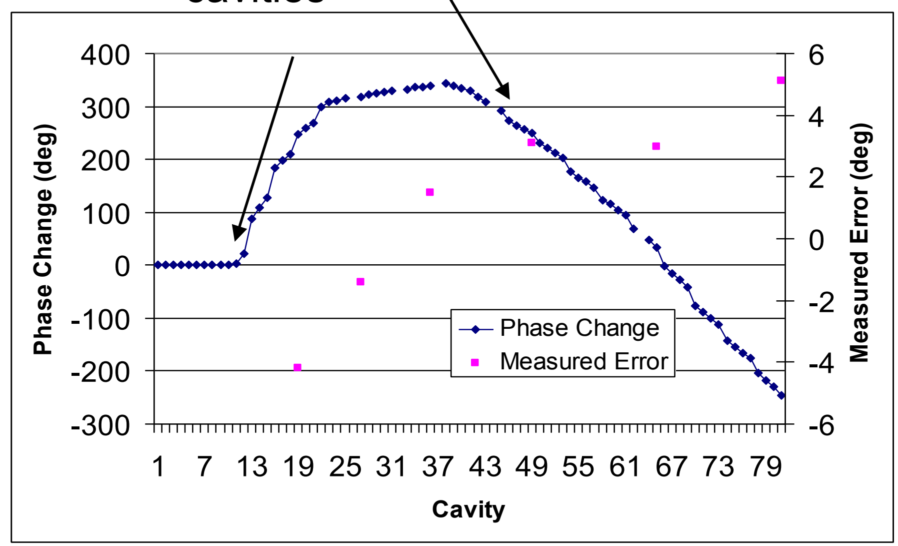
Superconducting Cavity Fault Recovery

- **A cavity fault recovery scheme is developed to adjust downstream cavity setup, to accommodate upstream cavity changes**
  - **Uses a difference technique, with initial beam based measurements**
  - **Successfully demonstrated and used at SNS**
    - **Could work in < 1 sec if needed**

Final cavity phase found within 1 degree, output energy within 1 MeV

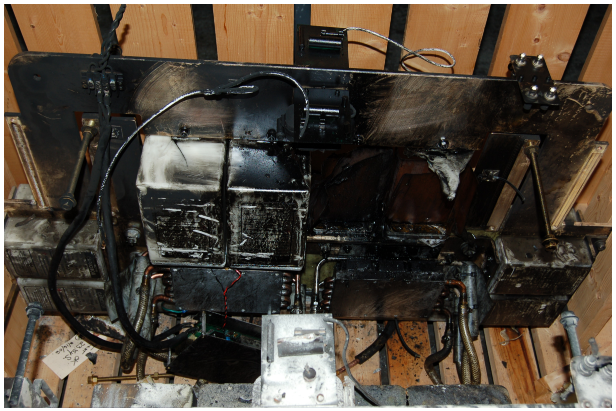


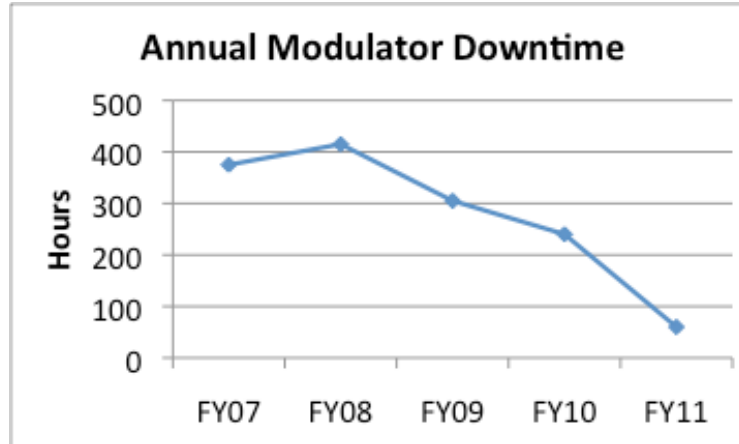
Turned on cavity 4a, reduced fields in 11 downstream cavities



High Voltage Power Supply System (HVCM)

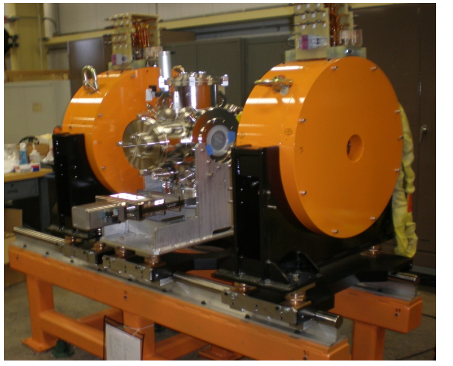
Initial experience – some "fireworks"

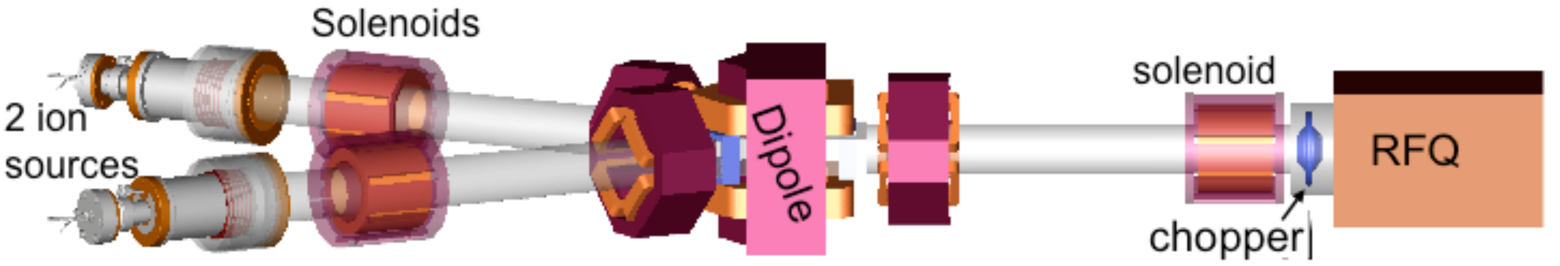




- **HVCM used new technology (IGBT)**
  - **Do not assume success with new technology**
- **Early on HVCM was a major down time problem**
  - **More robust components have greatly helped**
  - **For extreme reliability applications, need to consider hot-spare, independent power supply/klystron, etc.**

Ion Source reliability remains a concern

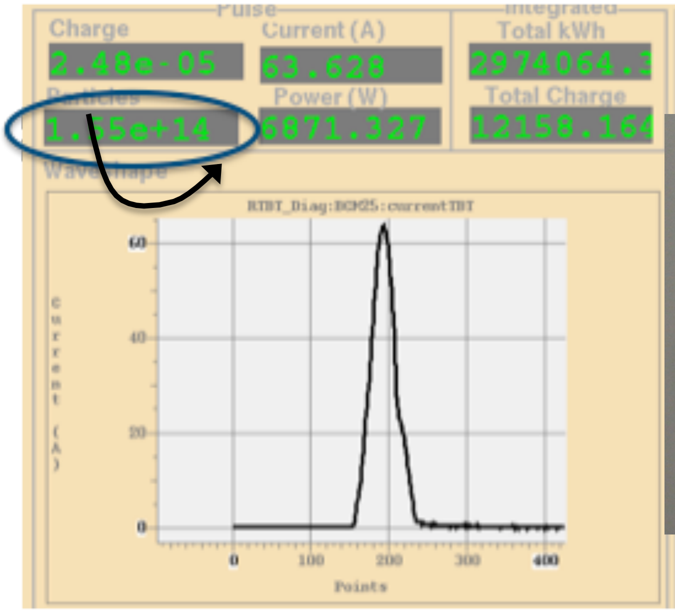




- At SNS the ion source is rising to the top of the reliability concern list
  – Long-term plan is to incorporate a dual source with a magnetic LEBT for redundancy

Ring experience has been very positive

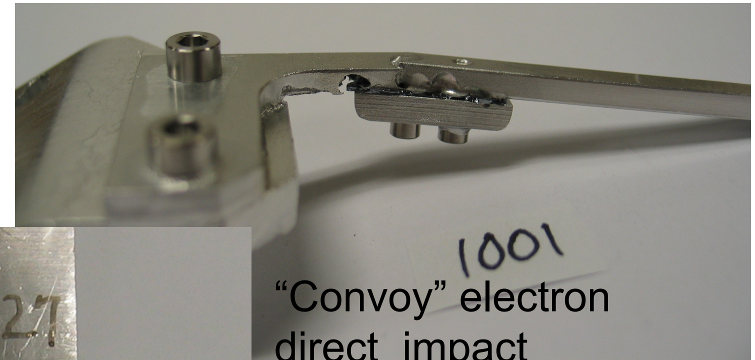
- **World record intensity for protons accumulated in a Ring**



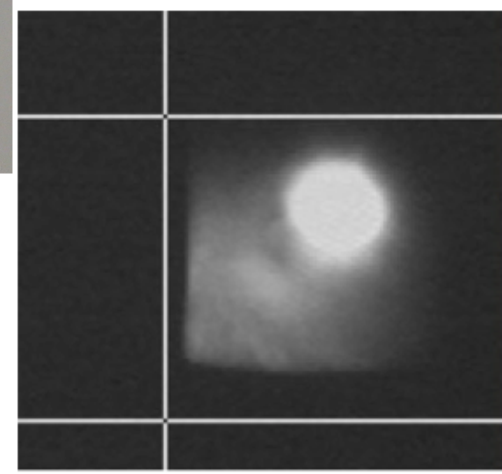
We have not been limited by:

- Beam instabilities
- Space charge induced beam loss

Foil bracket issues

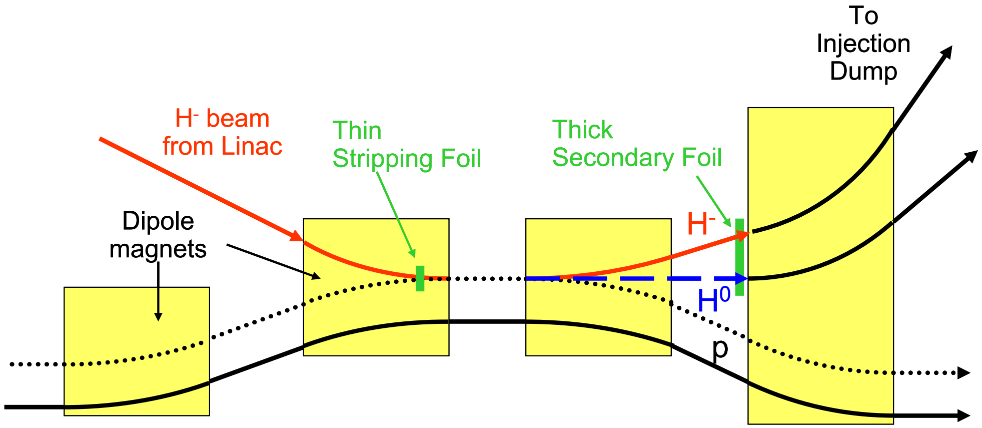


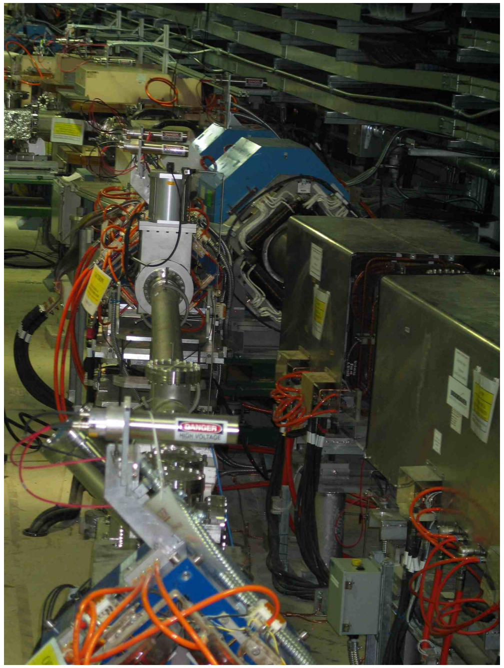
"Convoy" electron direct impact



Glowing foil at 1 MW

Ring Injection: More Difficult than Originally Envisioned

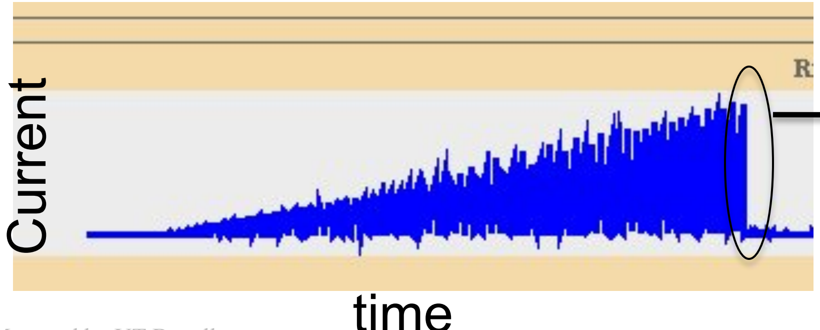


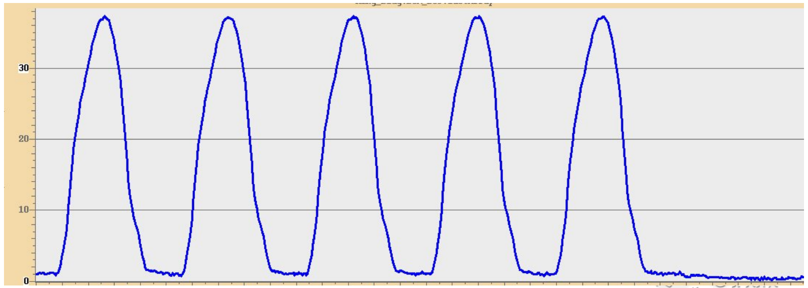


- **Need to handle clean transport of injected beam, circulating beam, un-stripped H- beam and partially stripped H0 beam**
  - **Not much space**
  - **Careful treatment of beam transport through 3-D fields**
  - **Fair amount of re-work in this area at SNS**
  - **Evaluating laser stripping as a future option**

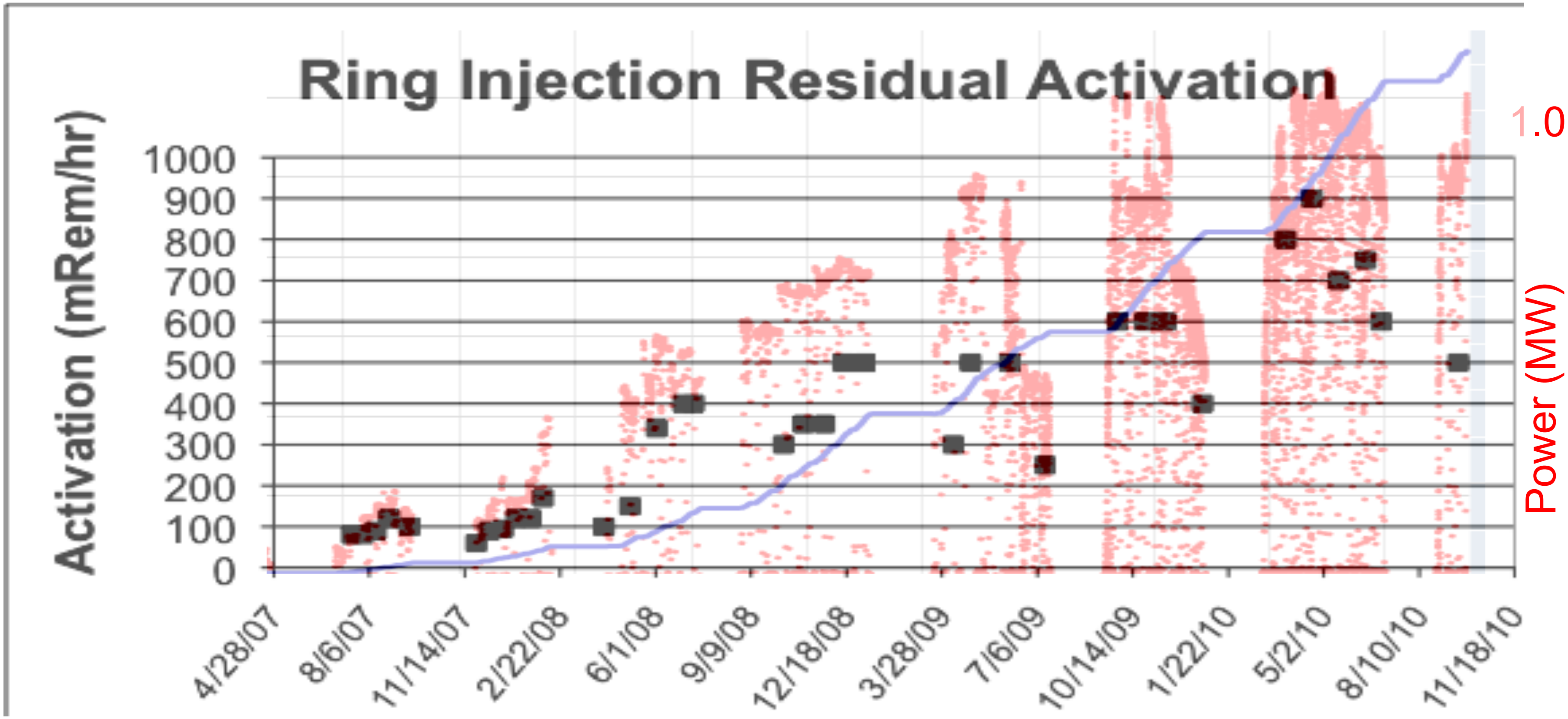
Clean Extraction from the Ring: No Problem

- We have only used second stage chopping for the past ~ one year
  - 1st chopper stage is slow rise time (~100 nsec) LEBT chopper
- We never implemented a planned "Beam-in-Gap" kicker to clean the gap
- We are running a smaller gap than initially planned (up to 75% beam vs. 68% beam)





Ring Activation History

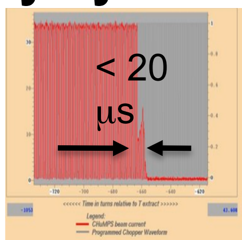


- Activation by the injection stripper foil is the highest in the SNS accelerator
- Close to activation expectations
- ~ Monotonic increase with beam power

Targets, Dumps, Collimators: More trouble than we imagined

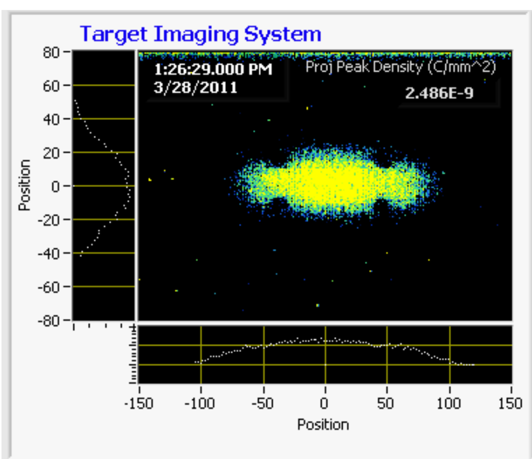
- High power operation requires good understanding and control of primary and waste beams
- Redundant safety systems – avoid excessive nuisance trips

Zoom-in on an errant beam wave-form

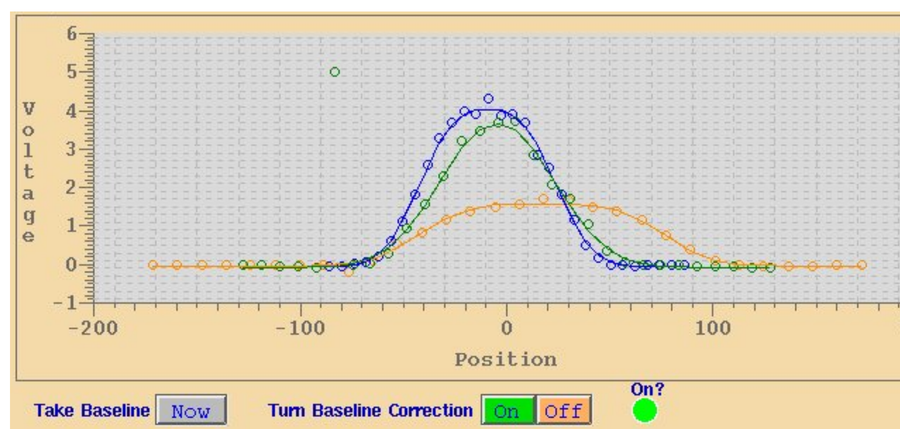


- **Fast beam shut-off systems:**
  - SNS errant beam to turn-off delay is ~ 20 μs
  - Can not buy these systems: custom hardware / software

Direct measurements (beam position, power density, …) are easier than….



…model based extrapolations from upstream measurements



Summary

- SNS is running a ~ MW proton superconducting linac
  - > 5000 hrs/year operation
  - Beam loss is not a limitation
    - Although we do see unexpected small loss levels
  - Reliability approaching 90%
    - Improving
    - Still have many more trips than requirements for other applications
      - Can use as a test bed for recovery concepts
- New technologies require shake-out periods
- A robust, intelligent control system is essential to success
- Customer requirements must be fully understood